Spatial Avian Wetland Habitat Assessment Model for the Eastern Shore Area of the Great Salt Lake

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Abstract

The Great Salt Lake (GSL) is surrounded by a vast network of dynamic and highly productive wetlands that serve numerous functions, including the provision of avian habitat for numerous migratory and colonial species. A Geographic Information System (GIS) *a priori* model framework was developed with the help of local avian and wetland experts. This model was used to evaluate changes in shorebird habitat for different lake levels and during different migratory periods. Classification methodologies for representing dynamic landscape variables using Landsat imagery were researched, tested and applied. A supervised maximum likelihood classification was used to classify wetland vegetation. The overall accuracy was a 69%, as compared to surveyed vegetation data. An unsupervised classification was used to extract shallow water depth regimes. This classification could not be validated due to a lack of available LiDAR data. Habitat suitability scores were developed for six functional shorebird guilds for the spring and fall migratory periods of 2000 and 2006. The resulting 12 habitat maps depict the entire GSL eastern shore area (ESA) landscape at a 30 meter resolution. These maps indicate that changes in habitat suitability scores are closely related to the fluctuating GSL shoreline. The maps are immediately useful for identifying areas appropriate for future survey work.

1.0 Introduction

1a. Problem statement

The wetlands of the eastern shore area (ESA) of the Great Salt Lake (GSL) provide essential staging areas for migratory shorebirds, waterfowl, and waterbirds from both the Pacific and Central flyways of North America (Paul and Manning, 2002). Multiple research endeavors have displayed that the quality of wetland habitat for a variety of avian species is increasingly at risk. This is largely due to urbanization in the communities of the Wasatch Front and the associated nutrient loadings from point and non-point sources (SLC, 2009).

At present, the availability and condition of avian habitat for the GSL ESA is not completely understood. While there are data and information available regarding the acreage and suitability of habitat for specific management areas within the ESA (Paul and Manning, 2002, Hoven et al., 2007 and BCMP, 2006) monitoring changing landscape conditions over the entire area, both seasonally and annually, is an enormous and expensive undertaking. The Great Salt Lake Water bird survey (Paul and Manning, 2002) successfully undertook such an endeavor and offers valuable information regarding bird counts for a variety of species in the GSL ESA at different times of year from 1997 through 2001. The results of this survey are reported for large polygon areas and are not necessarily reflective of the small-scale nesting and foraging habitat conditions that change with the fluctuating lake shoreline. A Geographic Information System (GIS) based model that can monitor changes in the quantity and quality of ESA wetland habitat conditions would be useful tool for managers and avian enthusiasts.

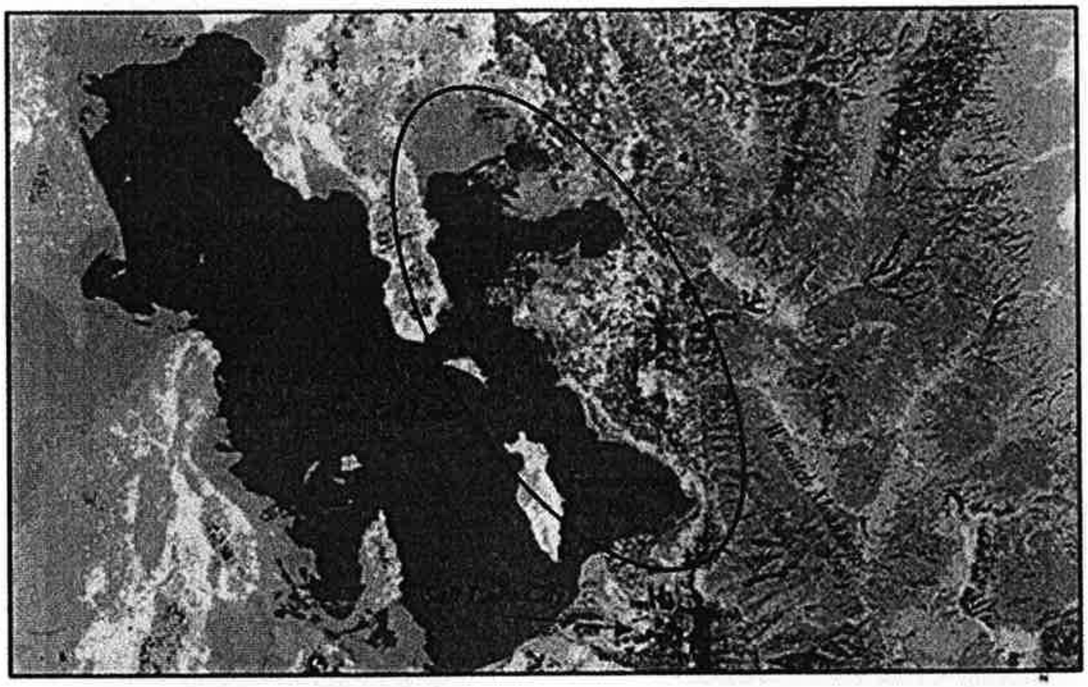

Figure 1. The Great Salt Lake Eco-region. The Eastern Shore Area of Great Salt Lake is circled in black (NLCD 2001).

Its large surface area and low topographical relief make the GSL very sensitive to climate-related fluctuations (Abarbenel et al, 2005). Long-term patterns and trends in the rise and fall of the lake level are difficult to predict, although lake level is essentially determined by the balance between the major inflows (three rivers and precipitation) and major outflows (evaporation and withdrawals) (Mohammed, 2006). In recent years, the lake level has dropped significantly due to persistent drought in the region. Nevertheless, the lake level continues to fluctuate erratically on a seasonal scale (Abarbenel et al, 2005). This erratic fluctuation has a significant effect on the depth of water, salinity concentrations, and wetland vegetation for areas located near the shoreline. Figure 2 displays the change in lake level as observed from 1992-2008.

bird groupings. Habitat suitability is a function of several anthropogenic and natural environmental variables represented with GIS data.

The relative influence of each variable on habitat suitability is defined as its variable strength (Vs). For example, if wetland class is considered more important than proximity to roads for a particular guild, it would be given a higher strength. Variable strengths in this model range from 0.1 to 1.

The range of values of each variable is translated into a series of weights (Wt) to indicate their relative suitability for each guild. For example, long billed curlew prefer to be near the shoreline, so locations within 100 meters of shoreline are weighted as 0.8, locations between 100 and 300 meters from shoreline are weighted as 0.1, and locations farther than 300 meters from shoreline are weighted as 0. As in this example, continuous variables are divided into ranges, which are each assigned a weight. Each value of ordinal and categorical variables is assigned its own weight. Variable weights in this model range from 0 to 1.

For each cell in a landscape, variable weights and strengths are multiplied and then summed to create a composite habitat suitability score (Figure 3).

Raster Calculation

(Vs)		(Wt)
1. Proximity to Shoreline (0.5)	X	<100 meters (0.3)
2. Vegetation (0.8)	X	< 50% Alkali Bulrush (0.3)
3. Roads (0.5)	X	> 30 m 2-lane Paved (0.2)
4. Wetland Class (0.9)	X	Emergent (.9)
5. Land Use (0.5)	X	Low Development (0.1)
6. Water Depth (0.8)	X	Very Shallow (0.3)

Score = 1.53

Likelihood of Species Presence in this Cell

$$\sum \left(\begin{array}{c}\text{Variable Strength}\\ \text{(Vs)}\end{array} \times \begin{array}{c}\text{Weight Gradients}\\ \text{(Wt)}\end{array} \right) = \begin{array}{c}\textbf{Weighted}\\ \textbf{Raster}\\ \textbf{Cell}\end{array}$$

Figure 3. Calculation of the habitat suitability score. Variables are assigned a "strength" (Vs), which relates the variables to one another, and a weight (Wt) to grade levels within each variable.

WILL	dry/saturated	short/med	moderate/dense		x	x	
LBCU	dry/saturated	short/med	moderate/dense	x		x	
SNPL	dry/saturated	none/short	sparse	x			x

Table 1: Foraging Preferences of Shorebirds in the Great Salt Lake Eastern Shore Area.

Species	Nest sites	Substrate	Salinity	Vegetation Height	Vegetation Density
AMAV	island/peninsula	open/exposed soil	alkaline/saline/fresh	short	sparse
BNST	island/peninsula	open/exposed soil	alkaline/saline/fresh	short	sparse
WILL	upland	open/vegetated	fresh/saline	medium	moderate
LBCU	upland/pasture	open/vegetated	fresh	short	moderate
SNPL	shore/upland	open/salt grass/gravel	alkaline/saline/fresh	none	sparse

Table 2: Nesting Preferences of Shorebirds in the Great Salt Lake Eastern Shore Area.

American Avocet (AMAV) and Black Necked Stilts (BLST)

American Avocets (*Recurvirostra americana*) and Black-necked Stilts (*Himantopus mexicanus*) both forage and nest in sparse, short vegetation. These species are generally found in shallow, muddy areas and are typically associated with brackish and salty water conditions. AMAV and BLST will nest on exposed soils on islands and peninsulas. Vegetated cover, water depth and proximity to shoreline are the most important indicators of suitable habitat for these species. In both spring and fall, the birds of this guild are highly associated with unvegetated playas and mudflats. During springtime, the presence of salicorina (pickle weed) in the playas becomes an important habitat indicator. In the springtime, proximity to shoreline is less influential, as the birds from this guild move to nest in depressional playas. In the fall, these birds are foraging in shallow to deep water (30 cm) and wet mud along the GSL shoreline.

Red necked Phalaropes (RNPH) and Wilson's Phalaropes (WIPH)

Red-necked Phalaropes (*Pharalopus lobatus*), and Wilson's Phalaropes (*Phalaropus tricolor*) are both mainly associated with the salty open waters of the GSL. RNPH nest in the arctic, while WIPH nest in intermountain west and the U.S. and Canadian prairies, but the GSL ESA is not a particularly significant nesting site for WIPH. Though they nest in small numbers in GSL ESA, both species are present during spring and fall in migration periods; therefore, these birds can be evaluated mostly for migratory habitats, not nesting. During migration, these birds are also associated with mixed emergent vegetation. They will not spend a lot of time in wetlands with mixed emergent, as they use this habitat mostly for drink fresh water. More commonly, the birds will be found floating in the deeper waters of the GSL. Deep open water is the most important variable controlling the distribution of this bird across the landscape.

Greater Yellowlegs (GRYE), Lesser Yellowlegs (LEYE), and Long Billed Dowitchers (LBDO)

Long-billed Dowitchers (*Limnodromus scolopaceus*), Greater Yellowlegs (*Tringa melanoleuca*) and Least Yellowlegs (*Tringa flavipes*) are all shorebirds associated with freshwater environments in the GSL ESA. In general, these birds are more associated with fresh water and mixed emergent vegetation. Birds queue in on the perimeter of the stands of rushes and *Phragmites* adjacent to open fresher water. They tend to congregate into the vegetation layer. Proximity to shoreline and water depths were variables added to the model. The GIS datasets used in the preliminary model (EPA, 2009) were developed exclusively for the Farmington Bay. For this project, all datasets were prepared for the entire GSL ESA. The GIS datasets created and used for this project are provided with this report. The model variables are summarized in this section and the final variables used for this project are depicted in Figure 4.

guilds for nesting and foraging habitat. Both "roadless" areas and proximity to roads are meaningful deterrents and indicators of suitable shorebird habitat for various guilds.

The Utah State Geographic Information Database (SGID, 1990) provides the base data for the Roads layer used in this study. The SGID roads represent different classes of roads in the state (e.g., four-lane highway, two-lane paved, dirt or gravel roads, and trails) at a 1:24,000 scale. The SGID dataset was clipped to the extent of the entire GSL ESA. The roads are buffered by 30 meters on either side to represent the typical right-of-way in Utah (BCPC, 2006).

Land use

The 2001 National Land Cover Database Land Cover (NLCD) classification (Vogelmann, et al, 2001) was selected to represent the non-wetland land cover classes. These data provide coverage for the agricultural, forested and developed areas located in the GSL ESA. Certain shorebirds will utilize non-wetland areas for foraging and nesting. For example, Long Billed Curlew will seek out hay/pasture and herbaceous land covers for foraging and nesting habitat.

Modifications to the NLCD dataset involved merging three forested classes into a single class; merging the four developed classes into two classes (high and low development); merging turf grass, golf courses, and parks into one class; and merging open space and barren land into one class. The NLCD dataset is currently being updated to reflect changes from 2001 to 2006. Updated data were not available for Utah at the time of this study. As a result, some model error may occur in portion of the study area that experienced a change in land cover between 2001 and 2006, most notably areas with elevations greater than 4,217 feet and located in the developing communities of the Wasatch Front.

Wetland vegetation

Wetland vegetation cover is a strong habitat indicator for all shorebird guilds. Playas and mudflats vegetated with *salicornia* (pickle weed) offer excellent foraging habitat. *Scirpus paludosus* (alkali bulrush), *scirpus acutus* (hardstem bulrush), and *typha latifolia* (cattails) offer important coverage and nesting habitat (Hoven and Miller, 2007). Mixed emergent wetlands are important indicators of shorebirds that utilize shallow, freshwater for nesting and foraging habitat. Upland areas are important for Willets and Long Billed Curlews. The presence of *Phragmites australis* (*Phragmites)* is a deterrent to many nesting and foraging species.

Ducks Unlimited (DU) carried out a comprehensive survey of the wetland vegetation coverage in the wetland diked areas around the Great Salt Lake based on digital aerial photography from 2006 and hard copy survey maps (DU, 2008). These data were employed as a base-line vegetation cover for this analysis. The DU polygon coverage is a fine representation of general vegetation coverage on the landscape. However, areas of the GSL ESA are omitted from the survey and the data represents a static "snapshot in time". Representations of these dynamic data are discussed in section 2c.

Wetland classification
The wetland classification dataset was used to partition the landscape into generalized wetland cover types that particular species are associated or disassociated with. For example, the WESA/LESA/BASA/BLPL guild is associated with depressional playas, but they are not associated with larger, dry fringe mudflats. The combination of the other variable datasets alone could not distinguish this subtle landscape dissimilarity. The wetland classification offered an opportunity to incorporate knowledge of a guild's association with large-scale generalized landscape patterns that are not represented by the other model variables.

A system was created that "generalizes" the 2008 National Wetland Inventory (NWI) dataset into functional classes for GSL ESA (EPA, 2009). The five classes developed for EPA study were: open water, fringe mudflat, impoundments, depressional playa, and freshwater emergent wetlands. For this project, a fifth class was created to represent freshwater outflows. These were palustrine wetlands located at the termination of conveyances, extruding from impounded or emergent wetlands, and fanning out across the fringe wetlands in a "crow's-foot delta" to the open water of the GSL. Freshwater outflows are important foraging areas for a variety of shorebirds. More detailed descriptions of the functional classification created for EPA, 2009 are presented in Appendix 8a.

2c. Classification of dynamic variables
Developing and evaluating methodologies for representing landscape variables that fluctuate over short time intervals was a key component for this research project. The general researched and applied methodologies are described in this section. More detailed descriptions of the preprocessing and classification steps are presented in Appendix 8f.

Proximity to shoreline, shallow water depth, and wetland vegetation are important indicators of foraging and nesting habitat for all shorebird guilds (Paul and Manning, 2002). These indicators were evaluated for their potential to be represented during the spring and fall migratory periods and at high and low GSL lake level conditions. Figure 5 displays a hydrograph with low and high periods indicated. Representing these dynamic variables in a GIS is challenging. They are dynamic landscape features connected to the ever-changing GSL lake level (Figure 5). For example, wetland vegetation cover is affected by seasonal changes in lake level and changes in the distribution of other vegetation patterns are noticeable on an inter-annual basis, particularly the invasive *Phragmites*.

scenes yields a full coverage for the Great Salt Lake. Four dates were obtained for the analysis. 06/06/2006 and 08/09/2006 were obtained to coincide with the DU vegetation survey. This ensured there would be training data available for a vegetation classification. 06/21/2000 and 08/16/2000 were obtained to coincide with the GSL Waterbird survey. This ensured there would be data available for attempting a validation of the final project maps. 06/21/2000, 06/06/2006, and 08/09/2006 were all collected from Landsat 4-5 TM. Landsat 4-5 TM did not provide a cloud-free coverage for August, 2000 and therefore, 08/16/2000 was collected from Landsat 7 ETM+ (NASA 2000 a, b, c, & d and NASA 2006 a, b, c, & d).

Image preprocessing

The image processing software used for this analysis was the ENVI 4.6 package (ITT, 2009). However, all of the processing steps outlined in the following paragraphs can be replicated using other image processing software packages.

The general methods for preprocessing are as follows: 1) layer stack and mosaic two same-date images; 2) resize the mosaic image to coincide with the spatial extent of the DU vegetation data; 3) mask out all agriculture, developed lands, and deep water areas; and 4) atmospherically correct the image using dark object subtraction (DOS) (Chavez, 1996 and 1998). Atmospheric correction accounts for factors that affect the amount of irradiance and radiance at a particular time so that temporal comparisons can be made under different solar azimuth and haze conditions. Figure 6 presents an example of the masked Landsat scene for the GSL ESA in fall, 2006.

in all bands were used to define the water mask. Results were checked against actual lake level measurements for the corresponding day at the USGS gauge in Saltair, Utah (USGS, 2009). Once the shoreline was delineated, the classification data was exported to ArcGIS and four buffers were created to represent important "zones" of shorebird use. The proximity buffers were set from the shoreline at 100 meters dry, 300 meters dry, 100 meters wet, and 300 meters wet (Paul et al., 2009).

There are alternative methods in the literature for automatic delineation of shorelines and lake boundaries from Landsat images that could be used in future research, including the Tasseled Cap Transform (Kauth and Thomas, 1976) and the Normalized Differenced Water Index (NDWI) (McFeeters, 1996; Zakariya, 2006).

Wetland classification

The only dynamic modification made for the wetland classification data was to adjust the boundary of the fringe zone and the dynamic open water zone. This was done by overlaying the extracted shoreline on the wetland classification, reclassifying the fringe areas below the elevation of the shoreline as open water, and above the shoreline as fringe. This modification was performed for each of the four dates.

Water depth classification

A k-means unsupervised classification was used to classify water depths. The classification was applied to the imagery for all four migratory periods. Water deeper than 12 inches was masked out using the USGS bathymetry data (Baskin and Turner, 2006), as were vegetation and other land cover types. This left a strip of shallow water and various shallow lakes and impoundments available for the unsupervised classification. During unsupervised classification, the iterative k-means algorithm was used to group together pixels with similar spectral signatures into classes. After 5 iterations, the resulting 20 classes were manually grouped into 5 shallow water classes with the aid of shallow water depth information and knowledge from a combination of data sources. The data sources included actual water depth estimates recorded in the Bear River Refuge impoundments (U.S. Fish & Wildlife Service, unpublished data), shallow water classification information provided in Keinest-Brown (2007), the USGS 1-foot bathymetry dataset (Baskin and Turner, 2006) and personal communication with local wetland and avian experts familiar with the water depths located on various areas of the landscape.

Vegetation classification

Wetland vegetation coverage is a strong habitat indicator for all shorebird guilds. The Ducks Unlimited survey data (DU, 2008) used in the preliminary AWHA model provides good coverage of the general vegetation patterns within the GSL ESA, but it represents static data from one year (2006). Inter-annual variation in the elevation of saline water from the GSL can dramatically influence vegetation patterns.

A supervised maximum likelihood classification was selected to map wetland vegetation. During the supervised classification, examples of each of the classes to be included in the map (training data) were manually identified before a computer program determined the

Table 4. Long Billed Curlew & Willet fall migration weights workbook				
Variables	**Vs**	**Fuzzy Operator**	**Wt**	**Final**
Description	*(Vs)*	*GIS Descriptor*	*(Wt)*	*weight*
Roads	0.20	Birds are present near a Four-Lane Highway	0.00	0.00
		Birds are present near a Two-lane Paved Road	0.00	0.00
		Birds are present Near Grade; Dirt Roads; Trails	0.50	0.10
		Birds are present with no roads	1.00	0.20
Land Use	0.80	Birds are present in High Development Areas	0.00	0.00
		Birds are present in Low Development Areas	0.20	0.16
		Birds are present in Golf Courses/Turf/Parks	0.00	0.00
		Birds are present in Row Crops	0.00	0.00
		Birds are present Hay/Pasture	0.80	0.64
		Birds are present in Herbaceous -Scrub Shrub	0.80	0.64
		Open Space/Barren Land	0.20	0.16
		Conifer and Deciduous Forests	0.00	0.00
Wetland Vegetation Cover	0.80	Open Water Vegetation (SAV/SAGO)	0.10	0.08
		Dominant Alkali Bulrush	0.10	0.08
		Dominant Catail/ Hardstem	0.10	0.08
		Dominant *Phragmites*	0.00	0.00
		Playa Mudflat Unvegetated	0.50	0.40
		Playa Mudflat Vegetated	0.50	0.40
		Mixed Emergent Vegetation	0.10	0.08
		Upland Vegetation	0.60	0.48
		Other	0.20	0.16
Water Depth	0.30	Dry	0.60	0.18
		Wet Mud	0.40	0.12
		Very Shallow	0.40	0.12
		Shallow	0.20	0.06
		Deep	0.10	0.03
		12+ inches – Open Water	0.00	0.00
Proximity to Shoreline	0.50	100 meters from shoreline - wet	0.80	0.40
		300 meters from shoreline -wet	0.10	0.05
		100 meters from shoreline -dry	0.60	0.30
		300 meters from shoreline -dry	0.60	0.30
Wetland Class	0.60	Dynamic Open Water Zone	0.00	0.00
		Fringe Mudflat Zone	0.20	0.12
		Depressional Playa Zone	0.70	0.42
		Freshwater Emergent Zone	0.30	0.18
		Impoundments Zone	0.30	0.18
		Nonwetland Zone	0.70	0.42
		Freshwater Outflow Zone	0.60	0.36

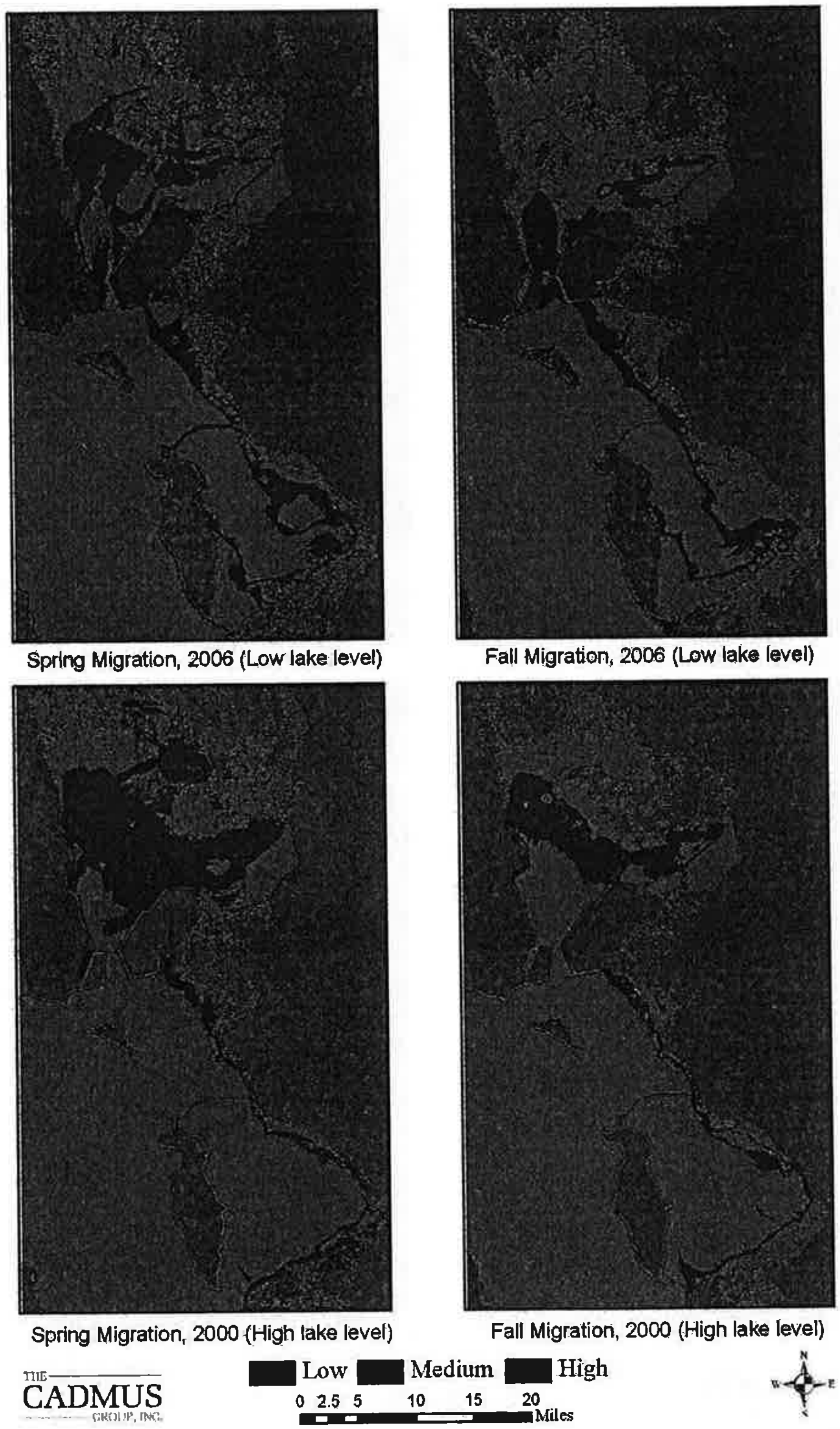

Figure 8. AVOC and BNST Habitat Suitability Scores in the GSL ESA. Red areas represent high habitat suitability scores, as determined by the combination of weighted landscape variables.

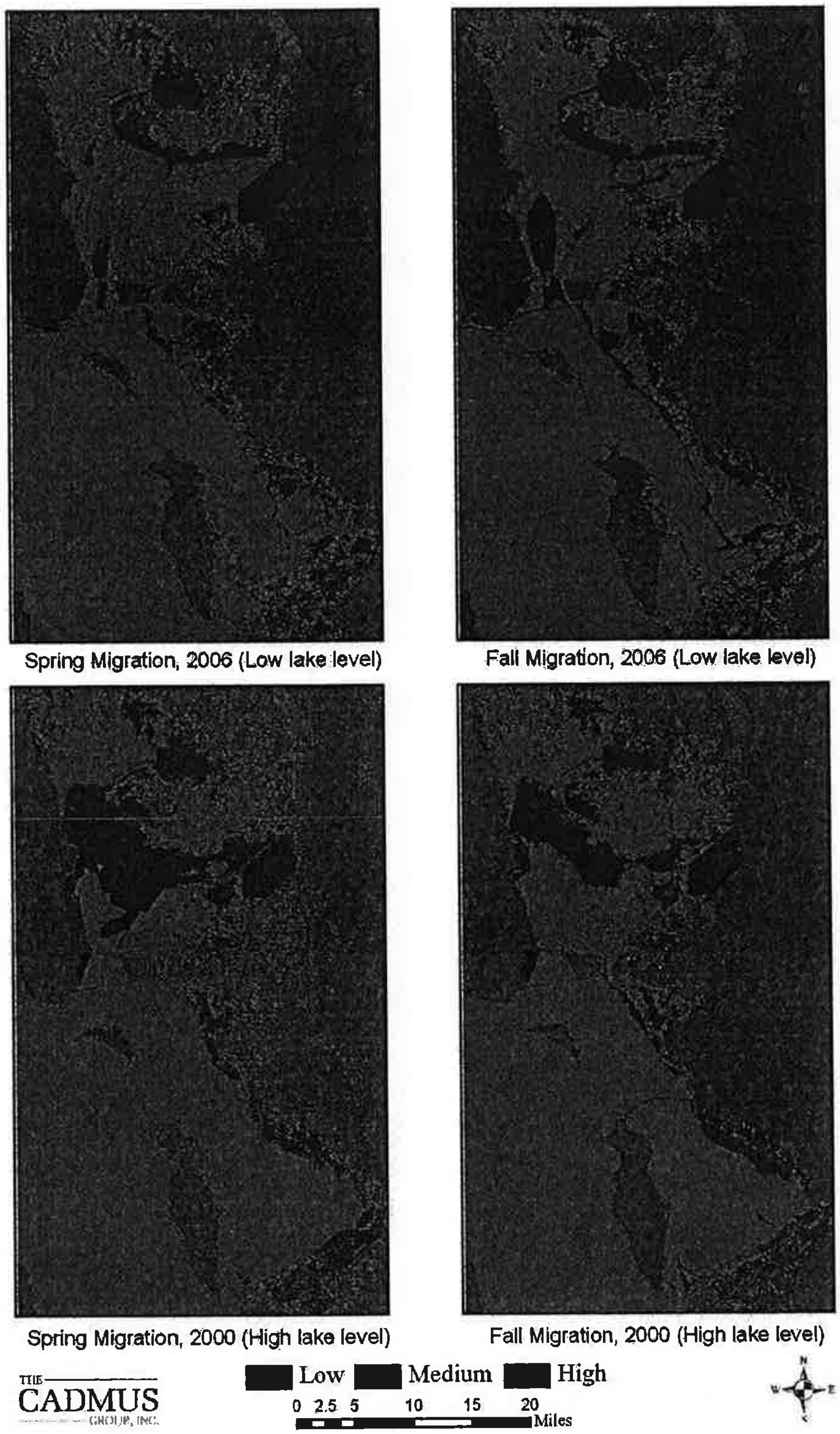

Figure 10. GRYE, LEYE, and LBDO Habitat Suitability Scores in the GSL ESA. Red areas represent high habitat suitability scores, as determined by the combination of weighted landscape variables.

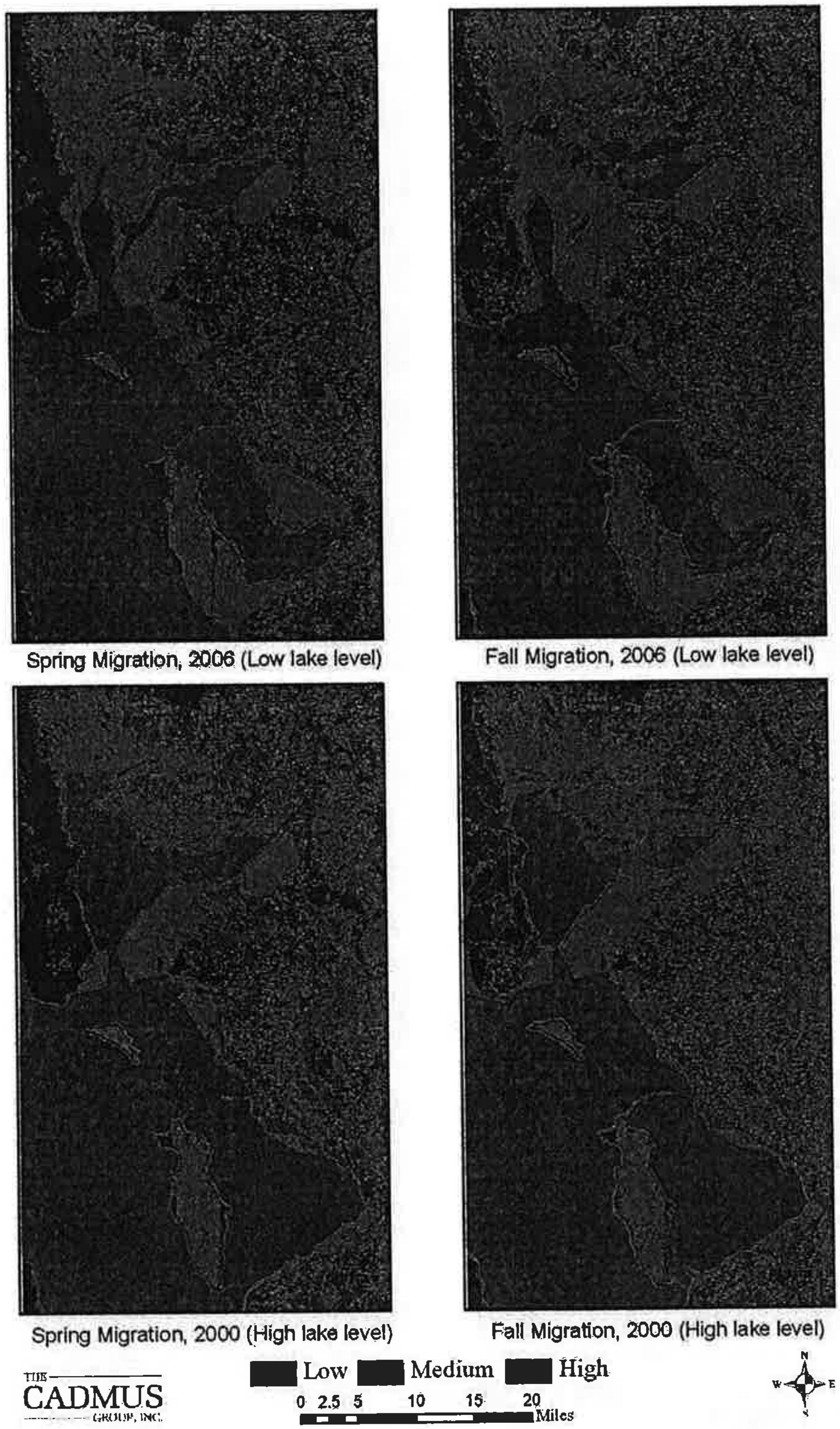

Figure 12. WILL and LBCU Habitat Suitability Scores in the GSL ESA. Red areas represent high habitat suitability scores, as determined by the combination of weighted landscape variables.

3b. Validation of final maps

The relative abundance of each functional guild across the study area is expected to be related to the habitat suitability scores created in this study. Data from the GSL Waterbird survey (Paul and Manning, 2002) were used to test this hypothesis. Because the survey areas are much larger than the spatial grain of the habitat maps, habitat scores had to be summarized for each survey area. Two methods were used to summarize the habitat scores, reflecting two hypotheses about how birds perceive the habitat quality of a large area. The first method was to use the mean habitat score for all pixels contained within the survey polygon. The second method was to use the 90^{th} percentile habitat score within each polygon, which assumes that birds will key in on patches of high quality habitat, even if they are surrounded by poor quality habitat.

Surveyed bird abundance data from two periods (June and August 2000) were standardized for each polygon by dividing by the area of the polygon to give bird density (number/hectare). The frequency distribution of bird densities among polygons is highly skewed, with many zeros, and a few very high values (Figures 15 and 16, Appendix 8b). Based on this distribution, zero-inflated count data regression (with log link) was used to evaluate the relationship between the summarized habitat suitability scores and bird density. Regressions were run with the pscl package in R.

For both summarization methods, little of the variation in relative abundance of most functional guilds across the study area was explained by habitat suitability scores (Table 7, Appendix, 8b). There are several possible reasons for this finding:

1. Variability in habitat quality *within* individual survey areas is comparable to variability *among* survey areas (Figures 15 and 16, Appendix 8b). Consequently, little statistical power was available to detect any relationships that may exist between habitat suitability and bird distributions.
2. The suitability of an area may be partially a function of its proximity to features that are nearby, but outside of the area, and are therefore not reflected in a polygon's score.
3. The density of birds in a particular area may be more the result of aggregative tendencies, rather than habitat suitability. This hypothesis is supported by the strongly skewed distributions of abundances among survey areas (Figures 15 and 16, Appendix 8b).

The survey data are single observations that capture one moment in the stochastic movements of bird populations. In principle, long-term average distributions should be more closely tied to habitat suitability than these one-time observations.

4.0 Discussion

4a. Utility for survey design

The habitat maps produced by the AWHA model are immediately useful for selecting the size and location of future shorebird survey sites. While the GSL Waterbird survey change is determined mainly by the receding lake level, which is connected to the persistent drought that affected northern Utah during this period. The lake level dropped approximately 10 feet from 2000 to 2006. Consequently, the relocated shoreline and shallower water depths throughout the GSL ESA allowed large swaths of playas and mudflats to emerge and become vegetated with pickle weed. The increased acreage of playas and mudflats for foraging augmented the quantity of high habitat scores for most shorebird guilds.

Despite the drought, there are notable areas that remained inundated and therefore provided refuge for shorebirds as the lake level receded. These areas are generally located where freshwater from rivers and conveyances discharges to fringe mudflats and eventually to the open water of the lake. Willard Bay, south of Bear River Refuge, the delta of the Weber River at Ogden Wildlife Management Area (WMA), and the outflows from managed impoundments on the south rim of Farmington Bay are examples of where water remained viable for supporting habitat in the dry-year, 2006.

Outflow areas may have remained inundated with freshwater, but the presence of *Phragmites* increased substantially from 2000 to 2006. *Phragmites* will out-compete other wetland vegetation types, particularly when water is less accessible. *Phragmites* spreads at an average perimeter expansion rate of approximately 5 meters per year (Phillips, 2005). In the GSL ESA, *Phragmites* seems to spread alongside conveyances and into freshwater outflows. This invasion along the conveyances may be associated with nutrient loading (Gucker, 2008). The increased presence of *Phragmites* and the decline of other wetland vegetation populations from 2000 to 2006 had a negative affect on the habitat scores for all guilds in the emergent and outflow areas.

Although less obvious, seasonal changes in habitat availability can also be distinguished by comparing maps for each year. Springtime storms and snowmelt deliver a large flux of water to the GSL ESA during the springtime migratory period. Over the summer, water is lost to evaporation and withdrawals. Barring an anomalous weather-related event (such as acute, short-term drought or intense rainfall and flooding over the course of a summer), this seasonal trend of lake level decline from spring to fall can be expected each year. As a result, seasonal patterns in the availability and suitability habitat for all guilds can also be anticipated.

4c. Error and uncertainty associated with variables

Vegetation classification

The accuracy of the vegetation maximum likelihood classification was evaluated using a confusion matrix with 300 random points generated from the DU survey data. These points were independent of locations used as training sites. Table 6 displays the results of this confusion matrix. The confusion matrix is presented in Appendix 8c.

Maximum Likelihood Classification	
Overall Accuracy	69.09%
Kappa Coefficient	0.585

was not feasible for this research project as LIDAR data has not been flown over the wetland and shallow open water areas of the GSL ESA.

Based on expert knowledge of water depths during different lake levels, the unsupervised k-means classification appears visually to be a representative classification. However, without LIDAR data, there are no means of validating for this dataset. The classes used for water depth do not represent actual depth in inches; rather the classes are broken down into a gradient of shallow water regimes (dry, wet mud, very shallow, shallow, and deep). It is not recommended that these shallow water classes be used alone for management decisions or bathymetry estimations until the classification can be validated with a legitimate LIDAR dataset.

Wetland classification
The only modification made for the wetland classification data was to adjust the boundary of the fringe zone and the dynamic open water zone. Adjusting this boundary is a small, but important detail for understanding how the landscape is affected by lake level rise. The fringe mudflats are commonly referred to as sheet-flow wetlands. Previously, this boundary between what is called mudflat and what is called open water was set arbitrarily using knowledge of lake level.

5. Recommendations

5a. Future survey design
An alternative to the *a priori* model approach used in this study is to use survey data to construct an empirical model. Empirical models avoid errors based on subjective judgments and can detect patterns that were not previously recognized. Construction of empirical models requires that survey data are collected at a similar spatial grain to the variability in habitat characteristics. Suitable survey data can also be used to validate *a priori* models. The results of this study indicate that the survey areas used in the GSL Waterbird Survey contain a wide range of habitat quality for most guilds (Figures 15 and 16, Appendix 8b). As a result, there was little chance of successfully validating the *a priori* models developed in this study with these data. Furthermore, these data are probably unsuitable for developing empirical models.

The habitat suitability maps developed in this study could be used to delineate areas for future surveys. Cluster analysis could be used to identify contiguous areas with relatively homogeneous habitat for one or more functional guilds. Survey data from these areas could then be used to refine the a *priori* models, which would lead, through an iterative process, to new habitat classifications and survey area delineations. This approach would capitalize on both expert knowledge and observation data, and would epitomize the philosophy of adaptive management.

5b. Obtain LIDAR data
As mentioned earlier, LIDAR data is not yet available for the wetland and shallow open water areas of the GSL ESA. The lack of fine elevation data to support shallow water bathymetry and water depth classification further supports the utility of a developing a

created and tested to adequately represent the nutrient variables in the fringe wetlands. Better definition of freshwater outflows may present a useful coverage for representing nutrient delivery in a GIS.

5e. Salinity concentrations and artesian springs

Salinity concentration is an important habitat variable for shorebirds. Currently, there are no numerical data or estimations of salinity gradients in the waters of the GSL and in the fringe wetlands. There are also no methods for representing salinity gradients for GSL in a spatial model. Collecting salinity data for different areas across the GSL ESA and developing a model that connects salinity gradients to lake-volume and/or water depth would be worth-while research endeavors. Incorporating a salinity gradient variable into these habitat predictions would help improve the accuracy of the predictions.

Artesian springs are important for shorebirds such as Snowy Plover. The birds will seek out freshwater extrusions to drink water. There are minimal data regarding spring locations in Davis County and Salt Lake County. These surveyed points for the most part do not extend down into the GSL ESA wetlands. A survey of artesian springs would be a useful undertaking.

6.0 Acknowledgements

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- Playa wetlands are classified by NWI as palustrine unconsolidated shore. Playas generally occur in topographic depressions (i.e., closed elevation contours) allowing for an accumulation of surface water.
- Fringe wetlands are classified in NWI as lacustrine emergent, lacustrine aquatic bed, and lacustrine unconsolidated shore. Fringe wetlands are adjacent to lakes, where the water elevation of the lake maintains the water table in the wetland. The boundary of the fringe wetlands in Farmington Bay is the edge of the seasonally flooded zone, as identified by NWI. This boundary between the fringe wetlands and the open water was modified seasonally based on the changing shoreline.
- The emergent wetlands are classified by NWI as palustrine emergent. Emergent wetlands are generally found in association with the discharge of groundwater to the land surface or sites with saturated overflow with no channel formation. The predominant source of water is groundwater or interflow discharging at the land surface.
- The impounded wetlands are a conglomerate of all NWI wetlands types in the GSL ESA region that are enclosed by engineered structures or are artificially flooded.
- Freshwater Outflows are palustrine wetlands that "intersect" with both the Open Water lake classes (lacustrine unconsolidated shore) and impoundments or riverine wetlands.

8b. Validation statistics

Guild	Period	Summary Method	Count Coef	Count p-value	Zero Coef	Zero p-value
AMAV	Spring	mean	-0.0013	NA	-0.0021	0.21
AMAV	Spring	90th percentile	-0.0021	NA	-0.0010	0.72
AMAV	Fall	mean	0.0033	NA	-0.0013	0.19
AMAV	Fall	90th percentile	0.0013	NA	-0.0006	0.55
GRYE	Spring	mean	-0.0571	NA	-0.0401	NA
GRYE	Spring	90th percentile	0.0026	NA	-0.0026	0.34
GRYE	Fall	mean	0.0003	1.3E-04	-0.0039	0.07
GRYE	Fall	90th percentile	0.0005	NA	-0.0065	0.07
SNPL	Spring	mean	-0.0075	0.014	-0.0002	0.94
SNPL	Spring	90th percentile	0.0024	NA	-0.0002	0.87
SNPL	Fall	mean	-0.0239	2.4E-07	-0.0079	0.18
SNPL	Fall	90th percentile	-0.0140	NA	-0.0051	NA
WILL	Spring	mean	-0.0024	<2E-16	0.0011	0.55
WILL	Spring	90th percentile	-0.0021	<2E-16	0.0002	0.88
WILL	Fall	mean	0.0008	0.181	0.0027	0.17
WILL	Fall	90th percentile	-0.0017	0.000	0.0001	0.94
WIPH	Fall	mean	0.0019	<2E-16	-0.0008	0.31
WIPH	Fall	90th percentile	0.0023	NA	-0.0007	0.47
WESA	Fall	mean	0.0384	NA	0.0060	0.36

Table 7. Results of zero-inflated count regressions with GSL waterbird survey data and habitat suitability scores. Coefficients and p-values are reported for the count component (poisson distribution with log link) and the zero component (logit link) of the regressions.

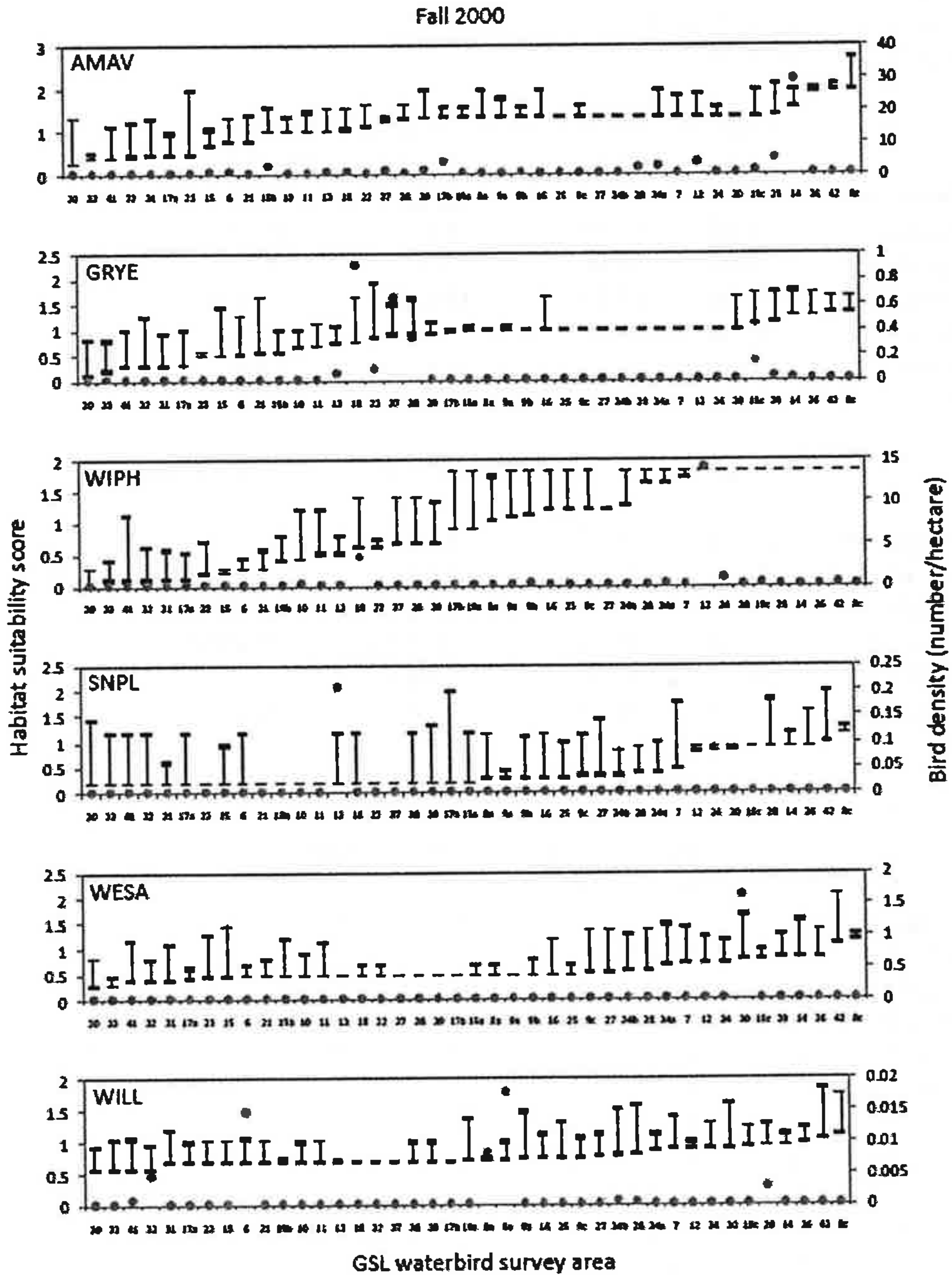

Figure 16. Summary of fall habitat suitability scores (black bars span the range between the 25th and 75th percentile) and bird density (blue dots) in GSL Waterbird Survey areas. Note that for many guilds, the variability in habitat suitability *within* areas is comparable to the variability *among* areas.

Total	16	25	285

Ground Truth	(Percent)				
	Phrag	Bul	Cat	Unveg	Veg
Unclassified	0	0	0	0	0
Dom Phragmites	57.14	15.38	50	0	2.9
Dom Bulrush	9.52	42.31	0	0	2.9
Dom Cattail/	9.52	0	50	0	1.45
Unvegetated P	0	7.69	0	82.46	18.84
Vegetated Pl	4.76	11.54	0	14.91	68.12
Mixed Emergent	14.29	19.23	0	0.88	1.45
Upland	4.76	3.85	0	1.75	4.35
Total	100	100	100	100	100

(Cont) Ground Truth	(Percent)		
	Mix	Upl	Total
Unclassified	0	0	0
Dom Phragmites	81.25	0	12
Dom Bulrush	0	0	5.45
Dom Cattail/	0	0	1.82
Unvegetated Playa	0	0	39.64
Vegetated Pl	0	8	25.45
Mixed Emergent	18.75	8	5.45
Upland	0	84	10.18
Total	100	100	100

8d. Phragmites error matrix

Overall Accuracy = (150/200) 75.0000%
Kappa Coefficient = 0.5000

Class	Commission (Percent)	Omission (Percent)	Commission (Pixels)	Omission (Pixels)
Phrag	31.06	9.00	41/132	9/100
Nonphrag	13.24	41.00	9/68	41/100

Class	Prod. Acc. (Percent)	User Acc. (Percent)	Prod. Acc. (Pixels)	User Acc. (Pixels)
Phrag	91.00	68.94	91/100	91/132
Non phrag	59.00	86.76	59/100	59/68

Ground Truth (Pixels)

Class	Phrag	Non Phrag	Total
Unclass	0	0	0
Phrag	91	41	132
Non phrag	9	59	68
Total	100	100	200

Export Joined Rasters to Grid files

1. Right click the first variable
2. Select "Data → Export Data…"
3. Set the cell size as 30 X 30
4. Set the location (workspace) to the "Joins" folder for the season/year of interest (i.e., C:\AWHA\Fall_06\Joins\
5. Set the format as "Grid"
6. Name the file noting variable, year and season (i.e., veg06_fall), then click "Save."
7. It is not necessary to add the resulting Grid files to the GIS project
8. Repeat Export for all variables

Run AWHA Model

Add Join data to model

1. Click the "+" sign next to the AWHA toolbox
2. Right click on the drop-down "AWHA" icon
3. Select "Edit"> a black and white flow chart will appear
4. Click "View" then "Zoom", then "Full Extent"
5. Click the Add data icon
6. Navigate to the Joins folder (C:\AWHA\Fall_06\Joins)
7. Hold Ctrl >select all variables> add all variables > they will appear as blue circles
8. Arrange each circle so is lined up with the associated lookup (i.e., water06_fall next to Lookup_water1)
9. Click the "Add Connection" Icon
10. Add connections from Variable to Lookup Box> the Lookup boxes should turn color
11. Click the Selection "Arrow" button
12. Double-click the "Lookup" Box
13. In the Lookup Field, scroll down to the Bird Guild of interest. Make sure that the season for the bird guild matches the season of the input data.
14. Leave the output raster name and location as is.
15. Repeat for each bird guild

Setup Final Calculation

1. Click the Single Map Algebra Block
2. Change the name of the calculation file to reflect the bird guild and season of interest. (e.g. C:\AWHA\Calculations\avocet_fall06). Do not change the location (path name) of the file.
3. Execute the model by clicking on the "Run" icon. (it's a sideways triangle)

Classifying Results

1. The output will be added to the Arc View Project
2. Right click the raster and select Properties>Symbology
3. Click on the "classified" display option, then click on the "Classify…" button.
4. Use the manual classification method to create class breaks that fit the data distribution histogram

Lmax for each band
Lmin for each band
Dark DNs from stats of resized image
E0 for appropriate date

4. Save file in notepad with the extension .PAR
5. Create a new folder called 'Dos_sr'
6. Run Dark Object Subtraction routine
7. Import header from original .BIP image
8. Select unsigned integer
9. Divide each band by 10000 in band math to get surface reflectance
10. Layer stack and save as 'name'_sr

Extract shoreline

1. Open sr_file
2. Load land cover mask
3. Load land cover mask
4. Use band 7 to extract the shoreline
5. Overlay a density slice to band 7
6. Create a class for slice that captures "deep water"
7. Denote water threshold using the 1 foot contour at the USGS gauge at Saltair, UT
8. Create a "zero" class on the density slice for the masked-out areas
9. Output water categories AND the zero category to an .EVF (Land Cover / Water)
10. Build a mask from the land cover/ water.EVF file

Classify vegetation using maximum likelihood classification

1. Classify surface reflectance (SR) image
2. Apply the land cover/ water mask
3. Create vegetation cover ROIs
4. Run maximum likelihood classification
5. Use the color map tool to create a legend

***Phragmites* classification**

1. Process mid-august data to capture flowering
2. Mask out water
3. Mask out agriculture
4. Create NDVI transform using band math (Band 3/Band 4)
5. Use density slice tool to classify all data above 0.6 as *Phragmites*

Classify shallow water

Create a mask for deep water and vegetation

1. Use USGS bathymetry to mask depths greater than 1 foot beyond shoreline
2. Classify 0 values as unclassified
3. Classify 1 to x as water (x is shoreline)
4. Export both classes as .EVF